

1
PRIORITY-DRIVEN DITHER2 Field of the Invention

3 The present invention is directed to the field of digital
4 printing and imaging. It is more specifically directed to the
5 reproduction of digitized documents.

6 Background of the Invention

7 Digital documents, containing a mixture of text and pictures
8 are proliferating. Similarly, the number of digital output
9 devices such as digital printers are increasing. A vast
10 majority of digital printers can print only in a bilevel mode,
11 either ink is printed or no ink is printed. The task of
12 converting digital documents into digital output on bilevel
13 output devices involves a process known as halftoning. In
14 halftoning the original continuous tone input is converted to a
15 bilevel image. Digital halftoning is used for printing a
16 picture (or more generally displaying a picture on some
17 two-dimensional medium). It uses small dots with a limited
18 number of colors such that it appears to consist of many colors
19 when viewed at a proper distance. For example, a picture
20 printed with black and white dots may appear to contain various
21 shades of gray when viewed at some distance.

22 Commonly used methods for digital halftoning include *dithering*
23 *algorithms* which use *threshold arrays* (also called *dither*

1 matrices) or *dither masks*. A fundamental problem in halftoning
2 is that text is generally not rendered well. Processing
3 pictures as text or text as pictures results in poor print
4 output quality. An example of this poor quality would be text
5 areas erroneously printed as halftones. This results in the
6 text looking blurred rather than sharp. It is desirable to
7 have an algorithm that can print both picture and text areas
8 well.

9 A possible solution is to segment the text and picture areas
10 and process them separately. The composite document containing
11 text and pictures is segmented into text and picture areas.
12 Only the picture areas are halftoned. This technique is time
13 consuming and error-prone in so much that the segmentation is
14 rarely performed with total accuracy. Furthermore, when there
15 are text areas within pictures the segmentation is not well
16 defined.

17 Goertzel and Thompson (US Patent 4,654,721) present a technique
18 for edge enhancement in halftones which assigns a number of
19 pixels to print in an area and orders the pixel values in a
20 larger area to determine where the printed pels should be
21 placed. The Goertzel-Thompson invention is based on lower
22 resolution input data and is not capable of reproducing the
23 level of image detail required by many applications.

24 Summary of the Invention

25 Thus an aspect of the present invention is to provide methods
26 and apparatus that can properly print both picture and text
27 areas using a halftoning technique based on an area-of-support.

1 Dynamic adjustments are made depending on whether the document
2 area contains text or pictures such that there is a smooth
3 (visually pleasing) transition between text and picture areas.

4 Another aspect of the present invention is to provide a
5 block-dither method, which involves a limited dependence on the
6 local surround of a pixel.

7 Another aspect of the present invention is to provide a method
8 which examines a digitized document, decides for each local
9 area how much gray the printer needs to put down, and
10 determines how these pixels are distributed spatially.

11 Another aspect of the present invention is to provide a method
12 which gradually switches from text rendering to picture
13 rendering in a manner that is locally adaptive over small
14 regions.

15 Another aspect of the present invention is to provide a
16 computationally fast method which does not rely on previously
17 used segmentation techniques which are error prone.

18 Brief Description of the Drawings

19 The foregoing and other aspects and advantages will be better
20 understood from the following detailed description of
21 embodiments of the invention with reference to the drawings, in
22 which:

1 Fig. 1, shows an example of how the image is divided into a
2 local region of interest (ROI) and its neighborhood in
3 accordance with the present invention;

4 Fig. 2 shows an example of a flow chart of the sequence of
5 decisions and computations made in halftoning in accordance
6 with the present invention;

7 Fig. 3 gives a detailed description of a priority driven dither
8 computation box in accordance with the present invention.

9 Description of the Invention

10 Halftone algorithms are either point operations (such as
11 dither) or sequential operations (such as error diffusion).
12 The current invention provides a block-dither method, which
13 involves a limited dependence on the local surround of a pixel.
14 An example embodiment of the present invention examines a
15 digitized document, and decides for each local area (say a 3x3
16 window or even 1x2) how much gray the printer needs to put
17 down. This determines the number of pixels to be turned on,
18 based on a calibration table. Then a decision is made as to
19 how these pixels are distributed spatially.

20 Consider a case in which M pixels are to be printed. In this
21 case M pixels are to be turned "on" with ink. A stack is
22 constructed which is initialized to the position sequence of
23 the gray values in a given 3x3 dither matrix. This stack
24 serves to prioritize the different pixels that could be printed
25 in the 3x3 window. The gray values in the 3x3 window are
26 conditionally sorted, as explained below, and the M black

1 values are assigned to the resulting lowest M gray levels. In
2 this way, a uniform gray level area is printed as a
3 pre-determined halftone pattern. The input data dictates the
4 number of pixels to be turned "on". In an embodiment, the
5 positions of the lowest gray values (darkest pixels) in the
6 input image are allowed to override the default sort order in
7 the stack. This achieves a smooth transition between halftones
8 and text. This results in better localization of features, in
9 that the printed pixel matches the features in the input image
10 that deserve the most ink. When a pixel in the image calls for
11 a pixel of ink, the method generates this ink pixel at the
12 correct location. This is advantageous to other halftoning
13 schemes such as error diffusion which cannot provide this
14 feature localization. A used herein a pixel value is the value
15 of that pixel's intensity or brightness.

16 Figure 1, shows an example embodiment of how an image is
17 divided into a local region of interest (ROI) and its
18 neighborhood. The computations for a given pixel are based on
19 the ROI and its neighborhood. In Figure 1 a region of interest
20 ROI, 102, is chosen from the input image, 101. The region in
21 this case is shown to be a 3x3 window. Other window sizes up
22 to or more than 128x128 are used in accordance with the
23 particular application and/or number of pixels in a text
24 character and/or image part. In general the window can have
25 any shape. It is advantageous to choose a regular shape such
26 as a rectangle or a circle to keep the size of the window
27 sufficiently small in order to capture local variations rather
28 than global variations. The neighborhood of the ROI, 103,
29 includes the additional image pixels from which we obtain
30 statistics. The image pixel values within the ROI are

1 transformed to binary values and placed in corresponding
2 positions in the output image according to the method described
3 in Figures 2 and 3. The entire image is covered by tiling the
4 ROIs so that adjacent ROIs don't overlap. For instance, in
5 Figure 1, ROI 102 is shifted by 3 pixels to the right for the
6 next iteration. Since the computations for each ROI are
7 independent of the computations for any other ROIs, these
8 operations can be carried out in parallel or in any sequence.

9 In the following discussion, a high dynamic range is said to
10 occur when the difference between the highest and lowest
11 intensity values is high, such from 150 to 240 (out of a 0 to
12 255 range for 8 bit pixel values). A medium dynamic range is
13 said to occur when the difference between the highest and
14 lowest intensity values is medium, such as from 50 to 149. A
15 low dynamic range is said to occur when the difference between
16 the highest and lowest intensity values is low, such as from 15
17 to 49. Values outside these ranges are either very low or very
18 high.

19 Example embodiments are given for four cases. These cases
20 consider different dynamic ranges of image intensity values in
21 the ROI and it's neighborhood. Those familiar with the art
22 will realize that the concepts of the present invention are
23 applicable to other cases and combinations.

24 A first case occurs when the image intensity values vary
25 over a high dynamic range. This typically occurs in text
26 areas which show large transitions between black and white
27 regions. Hence, a large difference between the minimum
28 and maximum values in the ROI and it's neighborhood is
29 useful to indicate the presence of text areas or very

1 coarse halftones. In these regions it is advantageous to
2 use a first halftoning rule to compute a dynamic threshold
3 and apply it to the ROI. This thresholding operation
4 generally renders text areas in a pleasing manner. It is
5 superior to straight forward halftoning of these text
6 areas which would cause these text areas to appear
7 blurred.

8 A second case to consider is when the image intensity
9 values vary over a low dynamic range. This is typical for
10 continuous tone gray areas which contain slowly varying
11 image intensities. In this situation, it is advantageous
12 to use a second halftoning rule for the rendering method,
13 which is to apply halftoning using a dither matrix. This
14 permits the gradual shift of the application of this
15 method to medium dynamic range areas.

16 A third case occurs when the image intensity values vary
17 over a medium dynamic range. If the dynamic range is not
18 clearly high or low, either of the above rendering methods
19 is not perfect. In this case a third halftoning rule is
20 employed to use a mixed procedure. In the third
21 halftoning rule the halftone procedure is modified by
22 first placing the printed pels in the darkest areas of the
23 ROI. The remaining printed pels are placed according to
24 the dither matrix. In general, a convention is used such
25 that a printed pel of "1" represents ink, corresponding to
26 dark areas. A printed pel of "0" represents no ink,
27 corresponding to light areas.

1 A fourth case occurs when all the image intensity values
2 are either very high or very low. In this case a fourth
3 halftoning rule is used such that all "0"s are printed at
4 the very high intensity values or all "1"s are printed at
5 very low intensity values.

6 Application of the halftoning rules is dependent upon the
7 particular case determined by examination of the intensity
8 values of each ROI and its particular neighborhood. The
9 computation carried out for each position of the ROI is
10 described with references to Figures 2 and 3. A next (or
11 first) ROI is chosen 201. We first compute the minimum, (min)
12 and maximum, (max.) pixel values in the ROI and it's
13 neighborhood 202. A determination is made as to whether the
14 fourth halftoning rule applies 203. If the minimum pixel value
15 is very high (as defined by the user for example) or if the
16 maximum pixel value is very low, then we apply the fourth
17 halftoning rule 204 and proceed to the next ROI.

18 If the fourth rule does not apply, we compute the difference
19 delta between the max and min values 205. We determine if
20 delta is less than a predetermined value, HalftoneLimit206. If
21 no, compute the threshold of the pixels 'T' within the ROI 207.

22 The threshold, T, is the average of the min and max values.

23 If the graylevel of a pixel within ROI is greater than T we
24 print a "0". Otherwise we print a "1" 208 and obtain a next
25 ROI 201. The HalftoneLimit is defined as the lower limit of
26 the high dynamic range, i.e. 150 for the examples given above.

27 If delta is less than the HalftoneLimit we use a priority
28 driven dither method 209 and obtain a next ROI if any 201.

1 Figure 3 shows an example of a priority driven dither method.
2 The first step in the dither method is to determine the number
3 of pels, N, to print in the ROI 302 for the given ROI 301.
4 This may be done in any number of ways. One example embodiment
5 takes the average gray value within the ROI and uses a lookup
6 table to obtain N from this average. A parallel step is to set
7 a predetermined order for printing pels in this ROI based on
8 some given dither matrix 303. It is assumed that we have a
9 large dither matrix of a size greater than the ROI. The
10 location of the ROI within the original image determines the
11 subset of the dither matrix which is used. This is performed
12 using the standard tiling operation performed in conventional
13 halftoning known to those familiar with the art. The next step
14 is to conditionally sort the pixels in the ROI based on their
15 pixel values 304. Conditional sorting is explained below.

16 Figure 4 shows an example of an initial sequence for printing
17 pels within an ROI 400 based on some dither matrix. Assuming a
18 uniform gray area, "1" represents the first pixel to be printed
19 401, "2" represents the second pixel 402, and so on until "9"
20 represents the last pixel 409 of the 3x3 ROI to be printed. In
21 accordance with the present invention, this initial sequence is
22 modified depending on the data present within the ROI. Assume
23 the ROI has an image 500 as shown in Figure 5. The image 500
24 shows a dark pixel in the lower right corner 501. The initial
25 sequence 400 is processed through a sorting technique to
26 produce a final sequence 600 shown in Figure 6. Note that the
27 dark pixel 601 in the lower right corner is now printed first
28 and subsequent entries maintain their otherwise relative
29 sequence order.

1 A sorting technique in accordance with the present invention is
2 described as follows. In all sorting we start with some
3 initial ordering of the items to be sorted. In a conventional
4 sorting technique, such as in a bubble sort, two adjacent items
5 are swapped if one is greater than the other. In the present
6 technique the same two adjacent items are swapped only if one
7 is greater than the other by a prespecified amount, n , as shown
8 in 304. When items are not swapped, the original relative
9 order is maintained. In this way, only significant differences
10 in item values result in reordering of the original sequence.

11
12 In situations where the ordering of the image intensity values
13 differ significantly from the ordering of the dither matrix, a
14 complete reordering generally occurs. In these cases pels are
15 printed only where the pixels are darkest. This is equivalent
16 to a threshold operation and is such as to provide a smooth
17 transition between a first case, high dynamic range, and a
18 third case, medium dynamic range. This operation directs ink
19 to those pixels that are the darkest such that it closely
20 follows details in the image.

21 In situations where most of pixel values are the same with only
22 a few exceptions, the initial printing sequence will be changed
23 only slightly. This provides a smooth transition between a
24 third case, medium dynamic range, and a second case, low
25 dynamic range.

26 It is noted that the current invention differs from the method
27 of Goertzel and Thompson (US Patent 4,654,721) in a number of
28 ways. In Goertzel and Thompson, the image goes through a
29 scaling operation, such that 9 pels are printed for each input

1 pixel. Therefore the pattern of the 9 pel area is determined
2 by the ordering of pixels in a larger 9 pixel area.
3 Furthermore, this was only done when a gradient criterion was
4 exceeded. In contradistinction the present invention does not
5 use the pattern derived from a larger area to determine the
6 pels printed in a smaller area. Also, in the present
7 invention, the ordering scheme is very different in that a
8 pre-assigned (priority) order is chosen. The order is changed
9 only if the difference in pixel values exceeds some threshold
10 value. The Goertzel-Thompson invention was generally based on
11 lower resolution input data and is thus not capable of
12 reproducing the level of image detail reproduced with the
13 method of the present invention.

14 It is noted that the present invention can be realized in
15 hardware, software, or a combination of hardware and software.
16 The present invention can be realized in a centralized fashion
17 in one computer system, or in a distributed fashion where
18 different elements are spread across several interconnected
19 computer systems. Any kind of computer system - or other
20 apparatus adapted for carrying out the methods described herein
21 - is suitable. A typical combination of hardware and software
22 could be a general purpose computer system with a computer
23 program that, when being loaded and executed, controls the
24 computer system such that it carries out the methods described
25 herein. The present invention can also be embedded in a
26 computer program product, which comprises all the features
27 enabling the implementation of the methods described herein,
28 and which - when loaded in a computer system - is able to carry
29 out these methods.

1 Computer program means or computer program in the present
2 context mean any expression, in any language, code or notation,
3 of a set of instructions intended to cause a system having an
4 information processing capability to perform a particular
5 function either directly or after conversion to another
6 language, code or notation and/or reproduction in a different
7 material form.

8 It is noted that the foregoing has outlined some of the more
9 pertinent objects and embodiments of the present invention.
10 This invention may be used for many applications. Thus,
11 although the description is made for particular arrangements
12 and methods, the intent and concept of the invention is
13 suitable and applicable to other arrangements and applications.

14 It will be clear to those skilled in the art that
15 modifications to the disclosed embodiments can be effected
16 without departing from the spirit and scope of the invention.
17 The described embodiments ought to be construed to be merely
18 illustrative of some of the more prominent features and
19 applications of the invention. Other beneficial results can be
20 realized by applying the disclosed invention in a different
21 manner or modifying the invention in ways known to those
22 familiar with the art.